10-12-06 IFW 2834

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| **Applicant:** | **Donald Gilbert Carpenter** | **Examiner:** | **N. Ponomarenko** |
| **Application No.:** | **09/935,936** | | |
| **Filed:** | **August 23, 2001** | **Art Unit:** | **2834** |
| **For:** | **ENERGY CONVERSION TECHNIQUE** | | |

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| Filing Date | August 23, 2001 |
| First Named Inventor | Donald Gilbert Carpenter |
| Art Unit | 2834 |
| Examiner Name | N. Ponomarenko |
| Attorney Docket Number | 021215/S |
| Total Number of Pages in This Submission | |

## ENCLOSURES (*Check all that apply*)

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  - [ ] Fee Attached
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  - [x] After Final
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| | | | |
|---|---|---|---|
| Firm Name | Langdale Vallotton, LLP | | |
| Signature | John P. Sinnott | | |
| Printed name | John P. Sinnott | | |
| Date | 10/11/06 | Reg. No. | 21,001 |

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## REPLY BRIEF SUPPLEMENT

Honorable Commissioner of Patents and Trademarks
Post Office Box 1450
Alexandria, VA 22313-1450

Sir:

Further in connection with applicant's Reply Brief filed in the above identified matter on August 28, 2006, it will be recalled that on page 10 of the Answer, the reference "A Text-Book of Physics", seventh edition, Longmans, Green and Co., 1920, page 87 was cited for the first time in this matter. Because this citation had to be obtained through an interlibrary loan service, additional time was required and applicant necessarily reserved the right to submit this Supplement on receiving a copy of the reference. The reference, moreover, was advanced in the Answer to support the position that:

> The sum total of all the energy within any given boundary, through which energy is not allowed to pass, remains constant. (Answer, page 9, lines 20 and 21).

Attached to this Supplement is a copy of the cited page 87 establishing the fact that this is a direct quote from the reference (Exhibit "A").

Attention, however, is invited to the balance of this passage:

> The above statement amounts to an enunciation of a doctrine which is practically the keystone of modern science, and is known as the *doctrine or principle of the conservation of energy.* (Author's Italics)
>
> It follows that if the boundary considered includes the universe, the principle of the conservation of energy amounts to a statement that the sum total of the energy of the universe is a fixed unalterable quantity.

Since 1920, the publication date of the reference in question, this "keystone of modern science", has been amended. It is now recognized that:

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> ...while energy conservation is a good local concept, as in equation (6.18), and can be defined more generally in the special case of an isolated system in asymptotically flat space, there is not a general global energy conservation law in general relativity theory. "Principles of Physical Cosmology", P.J.E. Peebles, Princeton University Press, Princeton, 1993, page 139 (Exhibit "B").

and

> The basic conservation principle then is the *conservation of mass-energy*. (Author's Italics, "Theoretical Physics, F. Woodbridge Constant, Addison-Wesley Publishing Company, Inc., Reading, 1958, page 317 (Exhibit "C").

Both of the foregoing references were cited (and copies supplied) in applicant's Appeal Brief filed in this matter on January 7, 2004. For ease in access, however, copies of these two references also are attached herewith.

Clearly, many fundamental advances in physics have been achieved in the years between the 1920 publication date of the cited "A Text-Book of Physics" and publications that issued as late as 1993.

The Watson et al. "Text-Book of Physics" citation, moreover, refers to boundaries through which energy is not allowed to pass. Present physical knowledge refutes this assumption of an energy impassable boundary. Illustratively, cosmic radiation pervades and passes through the entire universe, imaginary boundaries notwithstanding. The humble neutrino also passes through almost everything, interacting with other matter only rarely. Clearly, it is not possible to block out energy from "any given boundary".

The additional statement in the Watson et al. reference that "...the sum total of the energy of the universe is a fixed unalterable quantity" also fails to conform with current thinking in the field of physics. No one is sure of the universe' energy status wherein it might be increasing, decreasing or even remaining constant, but the flat statement that the energy of the universe is a fixed unalterable quantity is, at present, unsustainable. In this respect, please refer to the August, 2003 National Geographic Popular Science article (Exhibit "D") that also was submitted with the January 7, 2004 Appeal Brief.

In sum, the Board is respectfully urged to dismiss the Watson et al. reference from its consideration. Further, the Board is respectfully invited to recognize that the arguments advanced about the Conservation of Mass/Energy; energy of the universe, energy impenetrable boundaries; and the like are addressed by applicant only because they have been raised in the Final Rejection and in the Answer. Applicant respectfully submits that these arguments and speculations have little or nothing to do with the fundamental issue of the patentability of claims 1 through 8, inclusive, now on appeal. Applicant respectfully invites the Board's attention to 35 U.S.C. ¶102 which states:

> A person shall be entitled to a patent unless—

Section 102 then recites seven criteria, each of which, if met, would deny patentability for applicant's claimed subject matter. Inasmuch as not a single one of these seven criteria have been established in the course of the prosecution leading to this appeal, applicant is unquestionably entitled to receive a patent under the provisions of Section 102.

In a similar manner, not one of the criteria barring patentability under the provision of 35 U.S.C. ¶103 have been raised in this prosecution either, further entitling applicant to a patent grant.

Applicant respectfully submits that claims 1 through 8, inclusive, now on appeal are patentable and allowance of these claims is earnestly solicited.

Respectfully submitted,

John P. Sinnott

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Attorney for Applicant
Registration No. 21,001

October 11, 2006

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V. WATSON, C.M.G., A.R.C.S., D.Sc. (LONDON), F.R.S.

LATE PROFESSOR OF PHYSICS AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON

SEVENTH EDITION

REVISED BY

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LECTURER ON PHYSICS AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON

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# PREFACE

THE following pages are primarily intended to form a text-book suitable for a student who is already familiar with the very elements of the subject. Nevertheless it is hoped that the references to the most elementary parts of the subject are sufficiently full to prevent the necessity of the reader having to refer to any other book. It has been the aim throughout to make the demonstrations of the various propositions considered as elementary as possible. Thus a knowledge of the elements of algebra and Euclid and of the meaning of the trigonometrical ratios is all that is assumed. Those sections which, on account of their difficulty, or less importance as far as the sequence of the subject-matter is concerned, may well be omitted on a first reading, have been marked with an asterisk.

The settling of the order in which the various branches should be studied is a matter of some difficulty. Thus the strictly logical order, or at any rate the order which is most suitable from the standpoint of the nature of the phenomena dealt with, is often unsuitable in an elementary text-book. In such a work it is of the utmost importance that very little, if anything, should be taken for granted on account of the proof being postponed. The necessity for adopting an arrangement in which everything taken for granted in any section has been proved in the preceding sections, has been forced on me during my teaching work, at any rate for Elementary students. Thus in the following pages, in deciding on the order in which the subjects are dealt with, the question of the most convenient sequence from the point of exposition has been considered of paramount importance.

*cause* of gravitation. We are, however, unable to do this, and must content ourselves with saying that one portion of matter exerts force on another, and that it is to this force that their mutual potential energy when separated is due (compare § 64). We shall find that the theory that there is an all-pervading massless medium is necessary to explain the observed facts in heat, light, and magnetism and electricity; we are not at present, however, entitled to say that it is to stresses set up in *this* medium that gravitation is due.

**81. Kinetic Energy.**—Suppose that a body of mass $m$ is moving with a speed $v$, and that a force $F$ acting on the body in an opposite direction to that of the motion brings the body to rest after it has passed over a distance $s$. Then the work done by the body on the force while coming to rest is $Fs$. Now if in a distance $s$ the body loses a speed $v$, the acceleration must be $a=v^2/2s$ (§ 35). Also the force $F$ produces this acceleration in the mass $m$, and hence $F=ma=mv^2/2s$. But the work done by the force is $Fs$, that is, $\frac{1}{2}mv^2$. Hence the kinetic energy of a body of mass $m$ moving with a speed $v$ is $\frac{1}{2}mv^2$.

**82. Change of Form of Energy.**—The energy of a body is capable of changing its form from potential to kinetic, and *vice versa*. Thus suppose a stone of mass $m$ is supported on the edge of a cliff at a height $h$ above the base of the cliff. The potential energy is equal to the work done in raising the stone through a vertical height $h$. The force with which the earth attracts the stone is equal to the product of the mass of the stone ($m$) into the acceleration which the force would produce (*i.e.* $g$). Hence in raising up the stone it has been moved through a space $h$ against a force $mg$, and therefore the work done has been $mgh$, so that this is its potential energy.

If now the stone be allowed to fall freely, it will gradually lose its potential energy, but will at the same time acquire velocity and hence kinetic energy. After it has fallen a distance $s$, its speed will be given by the equation $v^2=2gs$, and hence its kinetic energy ($\frac{1}{2}mv^2$) will be equal to $mgs$. The potential energy is now $mg(h-s)$, since the stone is now at a height $(h-s)$ above the ground. The sum of the kinetic and potential energies is therefore equal to $mgs+mg(h-s)$ which is equal to $mgh$, the original potential energy. When the stone reaches the ground its potential energy is zero, but the speed which it has acquired is now given by $v^2=2gh$, and hence the kinetic energy ($\frac{1}{2}mv^2$) is equal to $mgh$, the same value as the potential energy at the start.

Thus, although during the fall of the body there is a gradual change of potential energy into kinetic, the total energy remains constant.

If the stone were thrown vertically upwards with a speed $v$, then to start with the kinetic energy would be $\frac{1}{2}mv^2$. This would gradually diminish as the stone rose and lost speed; there would, however, be a gain of potential energy. When the stone is at the top of its flight it comes for an instant to rest, so that its kinetic energy is now zero. It however possesses potential energy exactly equal in amount to its original kinetic energy.

**83. Principle of the Conservation of Energy.**—In the previous section we saw that although the *form* of the energy of the stone altered, so that it existed sometimes as potential energy, sometimes as kinetic energy, and sometimes as both together, yet the total quantity of energy was constant throughout. We shall in subsequent sections consider



many other forms in which energy can exist besides those already considered, and we shall find that these different forms of energy can be converted from one kind to the other.

When the stone reaches the ground it is brought to rest by impact with the ground, when it will apparently have lost both its kinetic energy and its potential energy. It is, however, found that the energy has not been *lost*, but has been transformed into another form, namely, that of heat, so that both the stone and the part of the earth it struck are warmer than they were before the impact. Joule has indeed shown, as we shall see later (§ 251), that in every case a given amount of work entirely spent in producing heat always produces the same quantity of heat, no matter how the conversion takes place. For instance, a given number of ergs of work which can be obtained from stopping a moving bullet, and hence destroying its *kinetic* energy, will produce a certain quantity of heat. The same number of ergs of work done in rubbing a button on a piece of wood will produce exactly the same quantity of heat. The energy in the form of heat possessed by a body is supposed to be due to the motion of its particles. If this be so, then the kinetic energy of the stone moving as a whole is converted, by impact with the ground, into kinetic energy of the *particles* of the body and the earth near the point of impact, the particles moving (probably backwards and forwards with a vibratory motion) with, on the whole, a greater velocity than before.

These observations may be generalised, for in every case, without exception, it is found that the sum total of all the energy within any given boundary, through which energy is not allowed to pass, remains constant, although the energy within the boundary may be transformed into any of the many forms in which it is capable of existing.

The above statement amounts to an enunciation of a doctrine which is practically the keystone of modern science, and is known as the *doctrine or principle of the conservation of energy*.

It follows that if the boundary considered includes the universe, the principle of the conservation of energy amounts to a statement that the sum total of the energy of the universe is a fixed unalterable quantity.

The principle of the conservation of energy also denies the possibility of "perpetual motion." By "perpetual motion" is meant the devising of some arrangement so that energy in the form of mechanical work can be produced without energy in some other form being used up by the machine. Thus if an engine could be made to do work on external bodies for an indefinite time, and thus give out energy, without being supplied with energy from without, or diminishing the stock of energy in all its various forms which it originally possessed, we should have a means of creating energy, and this is in direct contradiction to the principle of the conservation of energy.

**84. Availability of Energy.**—Although the total quantity of energy in the universe remains a constant quantity, so that whenever a given amount of energy in any one form disappears an exactly equal quantity of energy in some other form makes its appearance, yet there is, as far as man is concerned, a very important difference between the states of energy. Thus, to recur to the illustration of the stone on the edge of a cliff. By a suitable mechanical arrangement we can utilise some portion at any rate of the potential energy of the stone, and make the stone do work. For example, by attaching a string to the stone we can make it

# EXHIBIT “B”

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P. J. E. PEEBLES

# Principles of Physical Cosmology

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# Principles of Physical Cosmology

## P. J. E. PEEBLES

During the last twenty years, dramatic improvements in methods of observing astrophysical phenomena from the ground and in space have added to our knowledge of what the universe is like now and what it was like in the past, going back to the hot big bang. In this overview of today's physical cosmology, P.J.E. Peebles shows how observation has combined with theoretical elements to establish the subject as a mature science, while he also discusses the most notable recent attempts to understand the origin and structure of the universe. A successor to Peebles's classic volume *Physical Cosmology* (Princeton, 1971), the book is a comprehensive overview addressed not only to students but also to scientists active in fields outside cosmology.

The first part of the work presents the elements of physical cosmology, including the history of the discovery of the expanding universe. The second part, on the cosmological tests that measure the geometry of spacetime, discusses general relativity theory as the basis for the tests, and then surveys the broad variety of ways the tests can be applied with the new generations of telescopes and detectors. The third part deals with the origin of galaxies

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and the large-scale structure of the universe, and reviews ideas about how the evolution of the universe might be traced back to very early epochs when structure originated. Each chapter begins with an introduction that can be understood with no special knowledge beyond undergraduate physics, and then progresses to more specialized topics.

P.J.E. PEEBLES is Albert Einstein Professor of Science at Princeton University. He is a Fellow of the American Academy of Arts and Sciences and the Royal Society.

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The second step follows from the change of variables $x = \hbar\omega/kT$, with the dimensionless integral

$$I_- = \int_0^\infty \frac{x^3\,dx}{e^x - 1} = \frac{\pi^4}{15}. \tag{6.15}$$

Equation (6.14) is the Stefan-Boltzmann law. We will use the standard symbol, $a$, for Stefan's constant when it is easily distinguished from the expansion parameter.

The heat capacity of the CBR at fixed volume is $4aT^3$. If the matter consists of atomic hydrogen, the ratio of its heat capacity to that of the CBR is

$$\frac{1.5 n_B k}{4aT^3} = 4 \times 10^{-9}\Omega h^2, \tag{6.16}$$

where $n_B$ is the mean number density of hydrogen atoms (eq. [5.68]). This ratio is independent of redshift. Its small value explains why the CBR might be expected to have a closely thermal spectrum: at high redshifts, where the interaction between matter and radiation is appreciable, the matter relaxes to the radiation temperature, because the radiation has by far the higher heat capacity, and at thermal equilibrium the radiation spectrum remains thermal no matter how strong the interaction.

The ratio of the mean mass density in matter (eq. [5.67]) to the mass density in the CBR at the temperature in equation (6.1) is

$$\frac{\rho_b c^2}{aT^4} = 4.0 \times 10^4\,\Omega h^2 (1+z)^{-1}. \tag{6.17}$$

The redshift dependence follows because the energy density in the CBR varies as $(1+z)^4$ (because $T \propto 1/a(t)$ in eq. [6.4]), one power faster than for the nonrelativistic matter. With the lower bound on the mass density parameter $\Omega$ in equation (5.150), we see that at the present epoch the energy density in the radiation is a small fraction of the total. It follows that when the redshift is not too large the energy available from annihilation of mass by nuclear burning (or perhaps by the more efficient process of accretion by black holes) is sufficient to produce an appreciable perturbation to the radiation temperature. Whether this can have happend depends on whether there is a way to transfer the energy to the CBR while keeping the spectrum close to thermal. Some details on how this might happen are discussed in the next section and in section 24.

Two features in the standard interpretation of the CBR tend to be confusing. We have already noted in section 1 that the name for the standard model, the hot big bang, is misleading, for a bang suggests a localized explosion. In the standard picture the source of the CBR is not localized; the radiation is uniformly and isotropically distributed throughout the space we can observe. This agrees with



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the fact that the radiation is equally bright in all directions. The number density of photons is decreasing with time as $a(t)^{-3}$, not because photons are leaving the universe—there is nowhere else to go—but because the volume of space is increasing as $a(t)^3$.

The second confusing point is the nature of energy balance in the CBR. Since the energy density in blackbody radiation varies as the fourth power of the temperature, the expansion of the universe causes the radiation energy density to evolve as $\rho_\gamma \propto T^4 \propto a(t)^{-4}$. As indicated in equation (6.17), this is faster by one power of the expansion parameter than for the mass density in a gas of nonrelativistic particles such as baryons (eq. [5.19]). The number density of photons varies as $a(t)^{-3}$, as for baryons, but there is an extra factor of $1/a(t)$ for the redshift of the mean energy per photon. Another way to get the cooling law is to recall that the pressure of the radiation is $p_\gamma=\rho_\gamma/3$. With this equation of state, the local energy conservation equation (5.16) is

$$\begin{aligned}\frac{d\rho_\gamma}{dt}&=-3(\rho_\gamma+p_\gamma)\frac{\dot a}{a}\\ &=-4\rho_\gamma\frac{\dot a}{a}.\end{aligned} \qquad (6.18)$$

The solution is

$$\rho_\gamma \propto a(t)^{-4}, \qquad (6.19)$$

consistent with the Stefan-Boltzmann law (6.14) and the redshift law (6.4) for the radiation temperature. We see that the faster decrease of $\rho_\gamma$ compared to the mass density of a nonrelativistic gas is the result of the pressure work done by the expanding radiation. However, since the volume of the universe varies as $a(t)^3$, the net radiation energy in a closed universe decreases as $1/a(t)$ as the universe expands. Where does the lost energy go? Since there is no pressure gradient in the homogeneously distributed radiation, the pressure does not act to accelerate the expansion of the universe. (The active gravitational mass due to the pressure has the opposite effect, slowing the rate of expansion, as indicated in eq. [5.15]). The resolution of this apparent paradox is that while energy conservation is a good local concept, as in equation (6.18), and can be defined more generally in the special case of an isolated system in asymptotically flat space, there is not a general global energy conservation law in general relativity theory.

## Discovery

The history of the discovery and interpretation of the CBR is worth considering as an example of the curious paths progress in science can take.

Lemaître was the first to speculate on the physics and possible observable remnants of the very early stages of expansion of the universe. He imagined

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Waves, and Particles

*by*

F. WOODBRIDGE CONSTANT

*Jarvis Professor of Physics*
*Trinity College*

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again tells us that no material object can attain a speed equal to or greater than the speed of light.

Since objects in everyday life do not have speeds at all close to that of light, their variation of mass with velocity is not measurable. However, in the case of such small particles as the electron, proton, deuteron, etc., it has been possible to verify Eq. (14–27) experimentally. A beta particle from a radioactive source, or an electron accelerated to a high energy in a betatron, may have a speed sufficient for its apparent mass to be several times its rest mass. For the heavier proton to show a mass increase of the same proportion as that for an electron, the energy of the proton must be 1840 times as great; nevertheless our powerful proton accelerators, such as the synchrotron and cosmotron, reach energies well past the threshold beyond which mass variation must be taken into account.

**14–11 Einstein's mass-energy relationship.** We have seen that relativity requires that Newton's law of motion must be expressed as in Eq. (14–24) and that at the same time we must take $m$ to vary in accord with Eq. (14–27). With $m$ variable, Eq. (14–24) may be written as

$$\mathrm{F} = \frac{d}{dt}(m\mathrm{v}) = m\frac{d\mathrm{v}}{dt} + \mathrm{v}\frac{dm}{dt} = m\mathrm{a} + \mathrm{v}\frac{dm}{dt}. \tag{14–28}$$

We see that the equation $\mathrm{F} = m\mathrm{a}$ does not hold at high speeds if we take $m = m_0$, nor is it valid in general if we take $m$ to be the apparent mass. In fact, if v and a are in the *same* direction, we find (see problem 6 at end of this chapter) that

$$\mathrm{F} = \frac{m_0}{(1 - v^2/c^2)^{3/2}}\,\mathrm{a}, \tag{14–29}$$

where $m_0/(1 - v^2/c^2)^{3/2}$ is called the *longitudinal inertial mass*. Inertial mass is defined as the ratio $F/a$. On the other hand, if F is perpendicular to v, the inertial mass is found to be the same as the apparent mass given by Eq. (14–27).

From the conservation of energy principle, we take the kinetic energy of a moving body to be the work done by the force that accelerates the body from rest. If we retain the definition of work as force times distance, and assume linear motion, we have

NOTE

$$\text{K.E.} = \int_{v=0}^{v=v} F\,ds = \int_0^v \frac{d}{dt}(mv)\,ds = \int_0^v \frac{d}{dt}(mv)\frac{ds}{dt}\,dt$$

$$= \int_0^v v\frac{d}{dt}(mv)\,dt = \int_0^v v\,d(mv).$$

Substituting for $m$ from Eq. (14–27) and integrating, we get

$$\text{K.E.} = \int_{v=0}^{v=v} v\, d\left(\frac{m_0 v}{\sqrt{1 - v^2/c^2}}\right)$$

$$= m_0 \int_0^v \left[\frac{1}{\sqrt{1 - v^2/c^2}} + \frac{v^2}{c^2(1 - v^2/c^2)^{3/2}}\right] v\, dv$$

$$= m_0 \int_0^v \frac{v\, dv}{(1 - v^2/c^2)^{3/2}} = m_0 c^2 \left|\frac{1}{(1 - v^2/c^2)^{1/2}}\right|_0^v$$

$$= m_0 c^2 \left(\frac{1}{\sqrt{1 - v^2/c^2}} - 1\right). \qquad (14\text{–}30)$$

This is the *relativistic expression for kinetic energy*. If the first term is expanded by the binomial theorem, we find that

$$\text{K.E.} = m_0 c^2 \left(1 + \frac{1}{2}\frac{v^2}{c^2} + \frac{3}{8}\frac{v^4}{c^4} + \cdots - 1\right),$$

which reduces to the familiar $\frac{1}{2}m_0 v^2$ of Newtonian dynamics when $v \ll c$.

Equation (14–30) may be rewritten as

$$\text{K.E.} = mc^2 - m_0 c^2 = (m - m_0)c^2. \qquad (14\text{–}31)$$

Thus the kinetic energy of a moving body equals its gain in mass times $c^2$. We may also say that the apparent mass of a body increases linearly with its kinetic energy, so that an increase in mass is an indication and measure of the gain in kinetic energy. It is also found* that an increase in the potential energy of a system of particles is accompanied by a similar increase in mass equal to the gain in energy divided by $c^2$. Therefore we may say, in general, that *the gain (or loss) in the energy of a system is equal to the gain (or loss) in its apparent mass multiplied by* $c^2$.

We may go one step further and interpret the term $m_0 c^2$ in Eq. (14–31) as the *rest energy* of a body whose rest mass is $m_0$. This rest energy may

*See Richtmeyer, Kennard, and Lauritsen, *Introduction to Modern Physics*, 5th ed., pp. 69–70.



be regarded as a form of internal energy inherent in the nature of the particles out of which matter is composed. Then

$$mc^2 = \text{rest energy} + \text{kinetic energy}$$
$$= \text{total energy}.$$

If here we let $E$ stand for the total energy, we arrive at Einstein's famous *principle of the equivalence of mass and energy*.

$$E = mc^2. \qquad (14\text{–}32)$$

The value of any theory is measured by its success in predicting new results. In this respect Einstein's theory has been outstanding. In nuclear physics the equivalence of mass and energy has been put to the test repeatedly and it has always been confirmed. With the ability to measure the masses of atomic particles to a high degree of accuracy, nuclear physicists have been able to predict the energy changes accompanying nuclear and particle transmutations, and they have also been able to verify their predictions experimentally. The whole subject of nuclear energy (popularly called "atomic energy") illustrates the usefulness of the above principle. The energy exchanges involved in chemical reactions must also be accompanied by corresponding mass changes, but in this relatively low-energy field the mass changes are too small to be detected experimentally.

While chemical reactions and most nuclear ones involve a rearrangement of atomic or subatomic particles, the electron-positron and the proton-antiproton reactions are exceptions. In the latter two cases, physicists apply the mass-energy equivalence principle in various ways. Some say that when an electron and positron are annihilated, their rest mass converted into energy in the form of radiation called gamma rays; however, we shall see in the next chapter that gamma rays may be considered to be photons or light particles, which, because of their energy, carry with them the momental mass originally associated with the electron and positron. It would seem preferable to regard energy as a property of mass, or mass as a property of energy, the two being inseparable. The basic conservation principle then is the *conservation of mass-energy*.

Example. An electron and positron which are practically at rest come together and annihilate each other, producing two photons of equal energy. Find the energy and equivalent mass of each photon.

*Solution.* The rest mass $m_0$ of an electron is $9.1 \times 10^{-31}$ kg. This is equivalent (in the mks system) to the energy

# EXHIBIT "D"

ED 837882155 US

# Who Knew?

COSMOLOGY

## The Multiverse

*The universe as we know it just got more complicated*

The universe is bigger than we think. This seems to be a cosmic truth. Times change, theories evolve, astronomers see new things in their telescopes—and the universe always turns out to be vaster and more mind-boggling than anyone suspected. The most dazzling new theory holds that our universe isn't just big, it's one of many. It's like a bubble in a huge vat of beer, and every other bubble is another universe. (We like this image for some reason.)

Our concept of the universe used to be tidier. Ancient Egyptians thought the sky was held up by mountains at the corners of the Earth, and the stars were not so far away. But in the 17th century the telescope shattered that notion. Through the lens, the stars were countless, and space had depth. Stars were suns, rendered faint only by great distance. Then, in 1923, Edwin Hubble proved that mysterious, wispy things called nebulae are actually galaxies, or "island universes," outside our own.

New telescopes have since revealed ever more galaxies, and we've grown accustomed to living in Carl Sagan's cosmos, with *billions and billions* of galaxies, each utterly lousy with stars. But Sagan may have been underestimating.

A satellite called the Wilkinson Microwave Anisotropy Probe recently captured a glimpse of the residual radiation from the young universe, when there were no galaxies, only perturbations in a seething, expanding cosmos. The data give a precise age to the universe: 13.7 billion years, plus or minus 200 million years. Perhaps more significantly, the data support the idea of cosmic inflation, a variant of the big bang. The inflationary theory states that very early in the expansion the cosmos suddenly inflated, becoming unimaginably vast in a fraction of a second.

If inflation is correct, the universe really is more than a million trillion trillion trillion times larger than the already enormous visible cosmos. It's practically infinite in scale. You have to speak like a child to convey the idea—it's basically a gazillion times larger than we thought. And there's more: One variation of the inflation theory suggests that our universe is a calm bubble, a kind of "no inflation zone" within an infinitely large, chaotic, eternally inflating "multiverse," and that this multiverse contains countless bubble universes, some of which almost surely contain intelligent observers trying to make sense of their own crazy cosmos.

The problem is, a multiverse is a hard theory to prove. "Is this science? Not yet," warns cosmologist Michael Turner of the University of Chicago. "We can't test it."

But here's the most alarming part about living in a multiverse. If the cosmos is more or less infinite in scale, then statistical probabilities dictate that somewhere there's a planet identical to Earth, containing creatures identical to us, leading identical lives.

We don't buy it. Could there really be another world where Adam Sandler is a movie star?

—*Joel Achenbach*
WASHINGTON POST STAFF WRITER

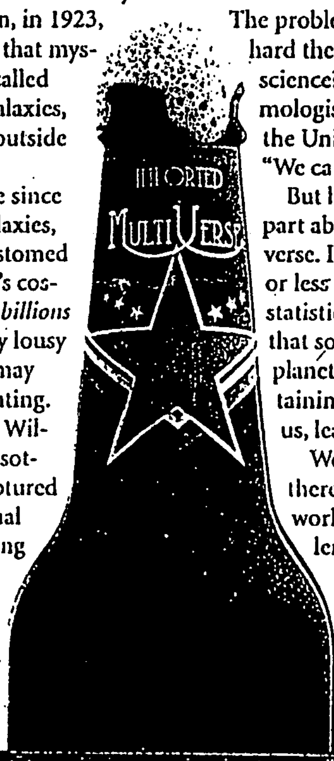

PHOTO ILLUSTRATION BY CARY WOLINSKY

**IT MATTERS**

**How far apart are those two planets?** Scientists measure length in meters. Kilometers and centimeters are just multiples and fractions (respectively) of the basic unit. But exactly how long *is* a meter? Since 1983 the International Bureau of Weights and Measures in Sèvres, France (keepers by treaty of the world's standard units of measurement), has decreed that a meter is precisely the distance light travels through a vacuum in 1/299,792,458 of a second. (How do you measure a hundred-millionth of a second? Don't ask.) That degree of precision matters. If astronomers measured a meter the way most Americans do ("Y'know, about a yard") imprecision would multiply prodigiously. Just between Earth and Mars you'd get a measurement mistake four million miles long.

—*Lynne Warren*

**WEBSITE EXCLUSIVE**

Learn more about the shape of the cosmos and find links to Joel Achenbach's work at nationalgeographic.com/ngm/resources/0308.